How Can Botnets Cause Storms? Understanding the Evolution and Impact of Mobile Botnets

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Outline

1. Motivation
   - Mobile Applications, Malware and Botnets
   - Research Issues and Our Focus
2. Preliminaries
   - Network and Attack Models
   - Problem Formulation
3. Results
   - Botnet Propagation
   - Mobile Botnet Impact
4. Conclusion

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2 Preliminaries

3 Results

4 Conclusion

Smart Phone, Mobile Malware, and Mobile Botnet

Smart Phones

- Powerful hardware, mobile operating systems, mobile APPs.
- Mobile malware has come into practice.

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Mobile botnet: A collection of malware infected nodes able to perform coordinated attacks.

- Ikee.B in 2009
- Android.Bmaster in 2011.

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- Ikee.B in 2009
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- [Traynor '09]: a botnet with sufficiently many infected phones is able to disrupt regional cellular services.

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The ways that a botnet propagates in mobile networks

- Centralized propagation: SMS/MMS, APPs in the market.
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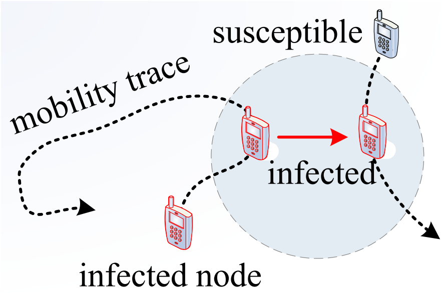

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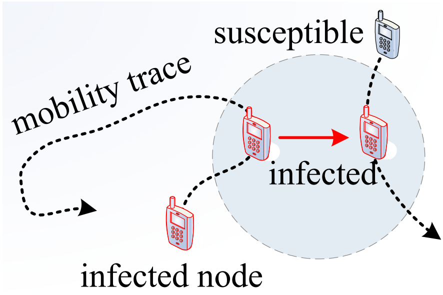
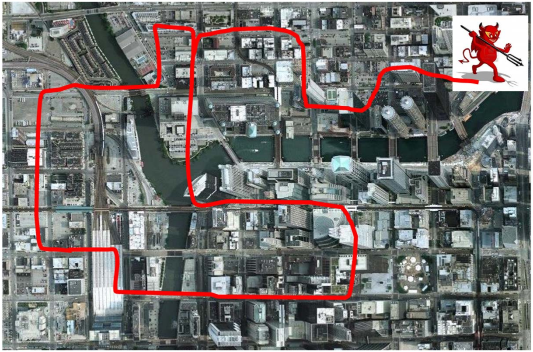


- Existing malware adopting proximity infection.
  - E.g., Mabir, Lansco and CPMC.

Research Question and Issues in the Literature

Question?

Can Mobile Malware via Proximity Infection Cause Storms?



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Answers

- Yes ([Carettoni'07, Yan'09, Wang'09]): Epidemic modeling and experiments
  - Infection storm: More and more nodes get infected as time goes.
- No ([Husted'11]): Simulations in realistic mobile scenarios.
  - Limited infection: the number of infected devices is limited with the relatively low vulnerability ratio.

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Somewhat discrepant results in the literature.

- Why: Node density, mobility, vulnerability ratio?

Research Question and Objective

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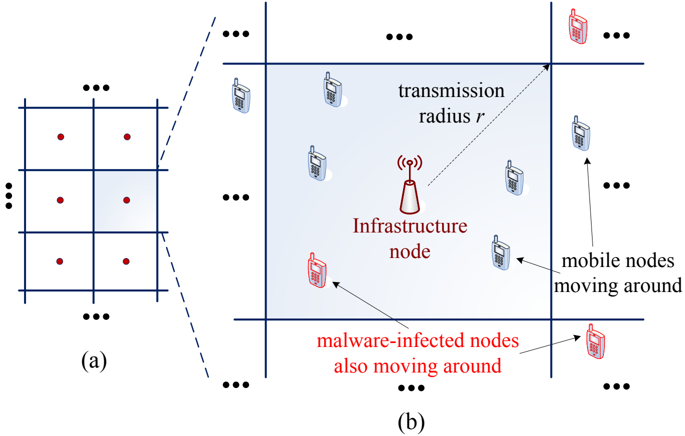
Objectives

1. Characterize how fast a mobile botnet propagates.
2. Investigate the denial-of-service impact of such a botnet.

Outline

Network Model

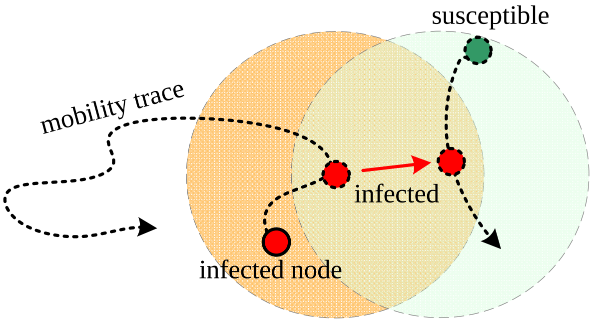
A hybrid network: infrastructure and mobile nodes.



transmission range r, mobile node density λ, network bandwidth B

Propagation Model: Proximity Infection

How to propagate malware from one node to another?



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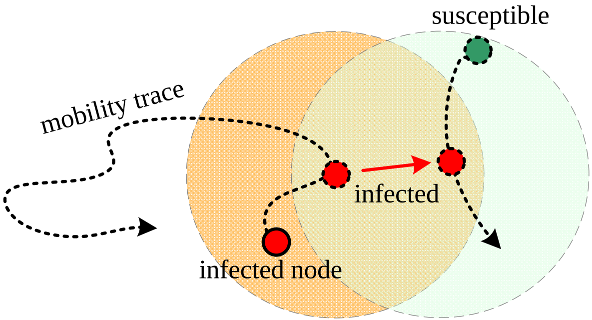

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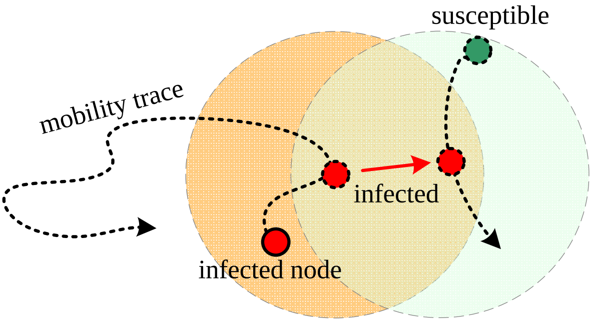

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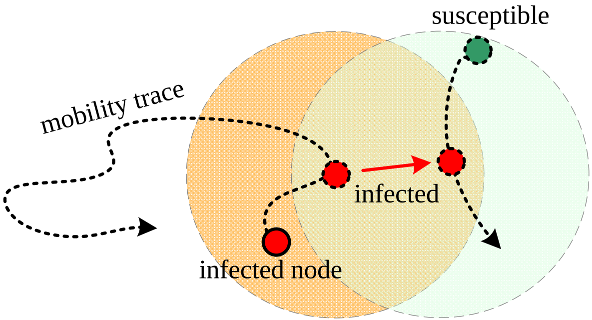

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2. Two nodes are in each other's transmission range (r).
3. Meeting time $>$ threshold.

Mobility Model: Generic Mobility

Realistic mobility always incurs spatial heterogeneity.

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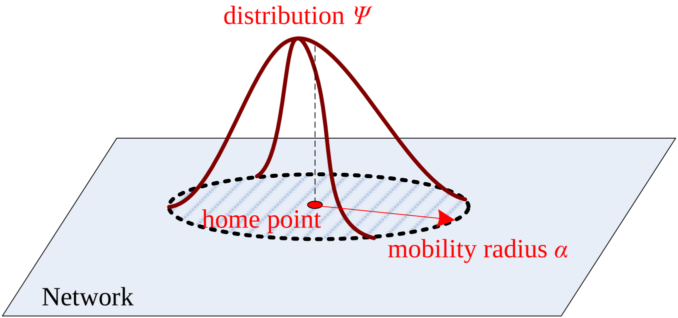
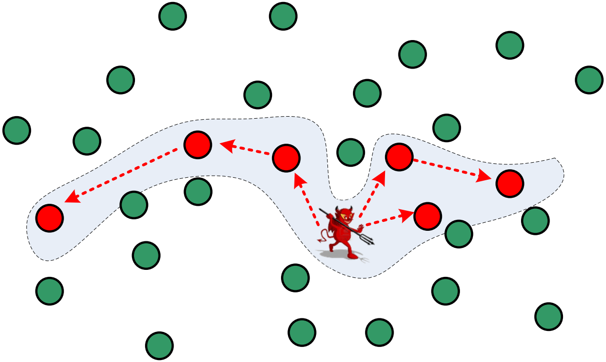


Problem Formulation and Performance Metric



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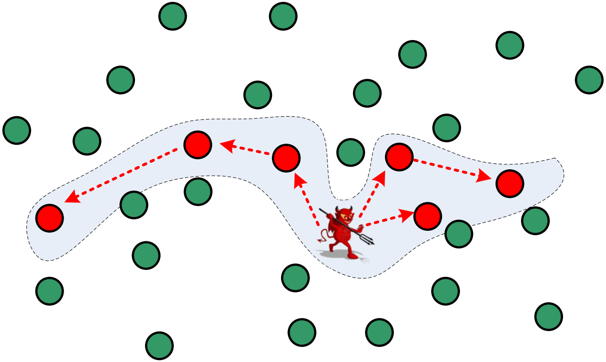

- Botnet $\mathcal{S}(t)$: the set of all infected nodes at t.

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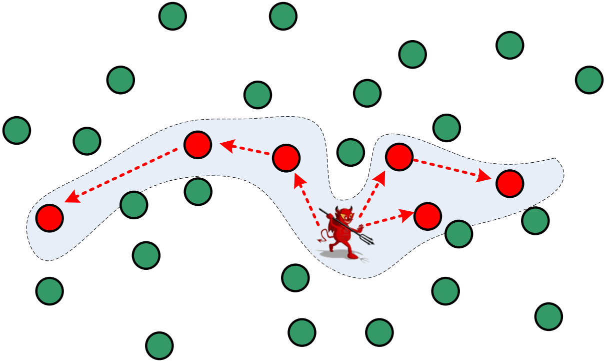


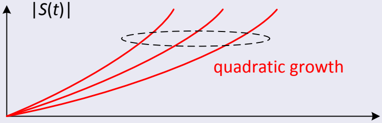
- Botnet $\mathcal{S}(t)$: the set of all infected nodes at t.
- Question: What is the botnet size $|\mathcal{S}(t)|$ at time t?

Outline

Theoretical Results

Theorem: Mobile Botnet Propagation

If the value of $\kappa\lambda(2\alpha + r)$ is sufficiently large, we have a botnet propagation storm: the average botnet size $\mathbb{E}|\mathcal{S}(t)| = \Theta(t^2)$.



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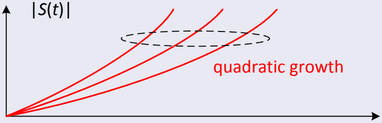
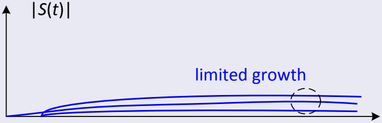


Otherwise, we have limited propagation: $\mathbb{E}|\mathcal{S}(t)| = \Theta(1)$.



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Direct Indications

1. Fastest rate of proximity infection: quadratic growth.
   - Internet botnets: exponential growth.

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Direct Indications

1. Fastest rate of proximity infection: quadratic growth.
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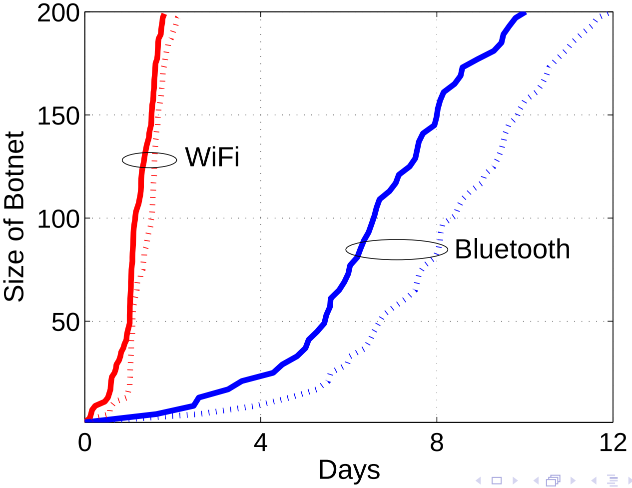
2. $\kappa\lambda(2\alpha + r)$ is the key
   - density λ, mobility radius α, transmission range r.
   - Practical scenario: density λ and transmission range r fixed
   - Sufficient mobility always triggers the $\Theta(t^2)$ infection!

Experimental Evaluation: Setups

- Mobility traces: EPFL/mobility data set: 300 cabs in San Francisco.

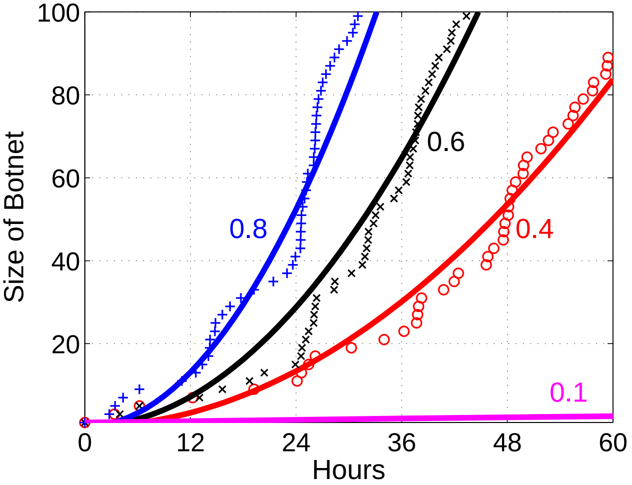
- Initially infected node: one cab is randomly chosen.
- Running period: 12 days.
- Wireless transmission range: Bluetooth (10m), WiFi (100m)
- Vulnerability ratio: 10% - 80%

The size of botnet with two different initially infected nodes and $\kappa = 80\%$.



Experimental Evaluation: Results

The size of botnet with different vulnerability ratios κ and WiFi.



Summary: EPFL Data Set

For different setups, we always observe the quadratical increase of the botnet size!

- Different vulnerability ratios
- Different transmission ranges
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Reason: Cab movements during 12 Days

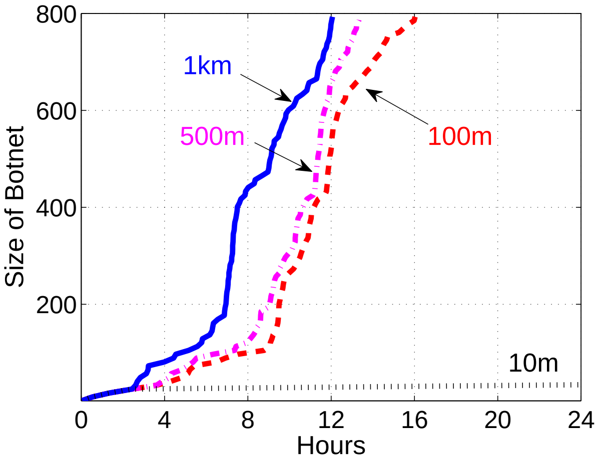
- sufficient mobility in San Francisco area.
- mobility radius α is large.

Experiments with Limited Mobility

- UDelModels: a tool to generate realistic mobility traces.
- Map: 2000 nodes in 2km×2km downtown Chicago, κ=60%, r = 10m (bluetooth),
- Mobility radius α=10, 100, 500, 1000m.

Experimental Results

The botnet size with different mobility radius α.



The Impact of Botnet Attacks

Quadratic growth: A botnet can become larger and larger

- Launching attacks targeting a mobile service. [Traynor '09]
- Infected nodes flood service requests.

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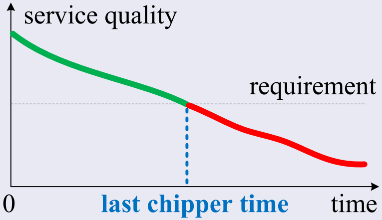
Question: If a botnet starts to propagate at time 0, how long the botnet is able to launch an attack to take down a service?

The Impact of Botnet Attacks

Performance Metric: Last Chipper Time

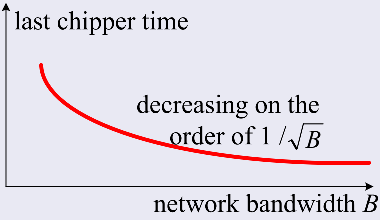


The last time that a required ratio ($\sigma < 1$) of mobile service requests can still be processed on time under the botnet attack,

$$T_l = \sup\{t \geq 0 : \mathbb{P}(D_p < d) > \sigma\}.$$

The Impact of Botnet Attacks

Theorem: Last chipper time decreases on the order of $1/\sqrt{B}$



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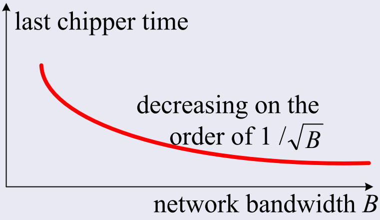

Increasing network bandwidth:

- improves network performance
- a botnet can propagate for a shorter time to disrupt a service.
    - less time to detect and respond the attack!

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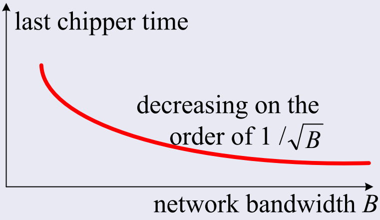
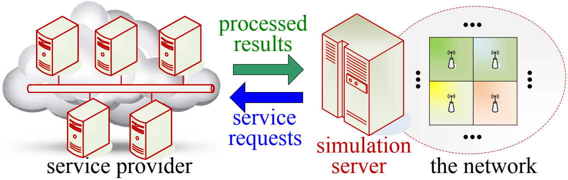


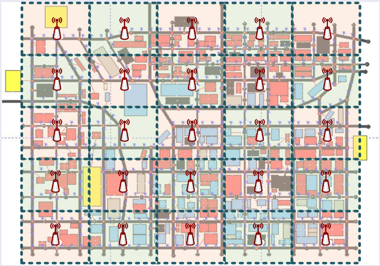
Example: LTE→LTE Advanced (10 times bandwidth increase).
Last chipper time becomes $1/\sqrt{10} \approx 1/3$ of the time in LTE.

Experimental Evaluation

Experimental setups



The Network: 2km$\times$2km downtown Chicago, 25 APs



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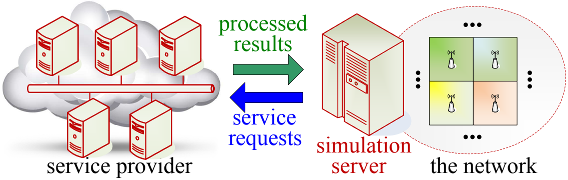
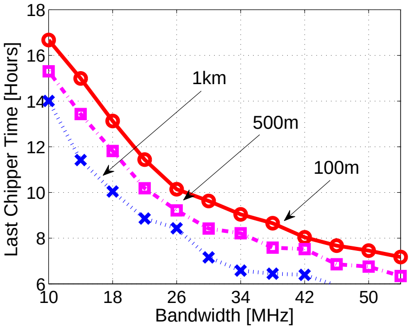


Service provider: small-scale

- 7 computers over Storm framework (real-time distributed processing).
- Service quality requirement: 90% on time.
- Service timing requirement: 2 seconds.

Experimental Results

The last chipper time with different mobility radius, κ=60%.



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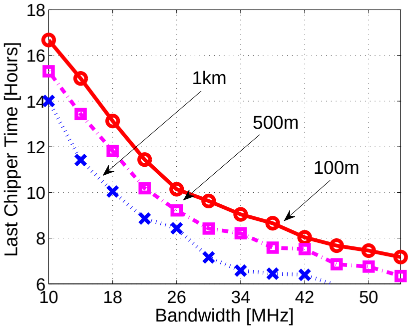

- Last chipper time decreases on the order of $1/\sqrt{B}$
- Increasing B increases the risk of service being disrupted.

Outline

Conclusion

1. We investigated how mobile botnets evolve via proximity infection and their impacts.

2. We found mobility can be a key to the size of a mobile botnet.
   - Sufficient mobility → the size increases quadratically over time.
   - Insufficient mobility → the size is bounded by a constant.

3. We defined the metric of last chipper time that offers quantitative risk assessment on potential denial-of-service impacts of botnet attacks in mobile networks.

Thank you!